

## THE NUMERICAL ANALYSIS OF NACA 0018 AIRFOIL: STUDYING THE EFFECT OF FLAP

ARMAAN ADITYA<sup>1</sup> & SRINIVAS. G<sup>2\*</sup>

<sup>1</sup> Student, Department of Aeronautical & Automobile Engineering, Manipal Institute of Technology,  
Manipal, Karnataka, India

<sup>2</sup> Assistant Professor Department of Aero & Auto Engineering, Manipal Institute of Technology,  
Manipal, Karnataka, India

### ABSTRACT

*An airfoil is basically a cross-section of the wing or a blade (in case of rotor or propeller). Flap is such a device which is used to increase the amount of lift generated by an airfoil. As the flaps are deployed the curvature (or camber) of the wing increases which leads to an increment in the lift coefficient of the wing. During take-off the required lift cannot be generated alone by the wings because of the slow speed and thus flaps are deployed. During flight when air flow over the wings starts detaching from the wing surface it leads to flow separation and thus stall of the aircraft. The stall is a severe phenomenon which can lead to sudden loss of lift and thus can be fatal for the aircraft. This paper deals with numerical analysis of NACA 0018 airfoil. Initially, 2D NACA 0018 clean airfoil has been modelled and simulated to obtain lift and drag coefficients. The results were validated by comparing it to standard data. Based on previous simulation a flap was added to the airfoil and then analysis was conducted to get lift and drag. Results obtained for both clean and flap airfoil were compared and the changes in lift and drag forces were tabulated. This paper will benefit and provide a base to researchers, aerodynamicists etc. who want to carry out work in the field of 2D airfoil. Standard SST  $k-\omega$  turbulence model was used in ANSYS Fluent to conduct the simulation.*

**KEYWORDS:** 2D Airfoil, ANSYS, CFD, Flap & Lift Coefficient

**Received:** May 18, 2019; **Accepted:** Jun 08, 2019; **Published:** Jul 16, 2019; **Paper Id.:** IJMPERDAUG2019107

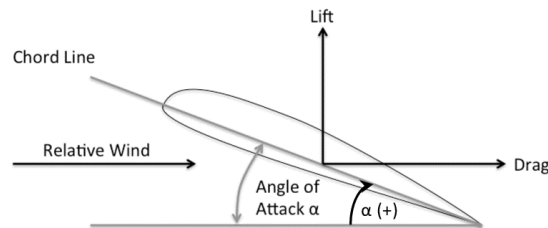
### INTRODUCTION

One of the major application of aerodynamics is the design and analysis of wings so that maximum lift can be obtained from the wings. For increasing the lift generated by a wing high lift devices are fitted. Angle of Attack (AOA) and shape of the airfoil are the major parameters affecting the lift on an airfoil. For decades researchers have been studying methods so that they can increase the lift generated by wings without putting on extra weight on the aircraft. The lift generated by a wing is affected by factors like wing area, flow velocity etc. Flaps are a kind of High Lift generating device which can be retracted when not in use so that they don't increase the drag in mid-flight. Flaps reduce the stalling speed of the aircraft and thereby reducing the minimum flight speed.

Once deployed the flaps increase the camber of the wing which increases the maximum lift coefficient of the wing. By deploying flaps the area of the wing also increases and an increase in the camber leads to increase in the wing drag also. This increment in the wing drag is of great benefit during approach and landing phase of the

aircraft. Flaps come in various designs and configurations each having their own advantages and a choice is made based upon the type and complexity of application. A few types of flap include plain flaps, slotted flaps, Krueger flaps, Foulner flaps etc. As flaps are to be used only for certain phases of flight in modern aircrafts the flaps are combined with a control surface named ailerons.

An aerodynamic force is generated when a wing (or airfoil) moves in air. This aerodynamic force acts in the rear direction at an angle to the direction of relative motion and this force can be resolved into two components as depicted in Figure 1.



**Figure 1: Forces Acting on an Airfoil [9]**

Drag is a component that resists the motion of the aircraft by acting in a direction opposite to aircrafts motion. Drag can be thought of as aerodynamic friction and the magnitude of drag depends on several factors. One of the major ways to reduce the drag is to make the airfoil as streamline as possible. By making design modifications like the addition of flaps the drag can be further reduced. The efficiency of flaps in reducing the drag and also increasing the lift generated depends on several factors like position, flap angle and length of the flaps. Rigid flap fixed at a flap angle of  $23^\circ$  was considered for analysis.

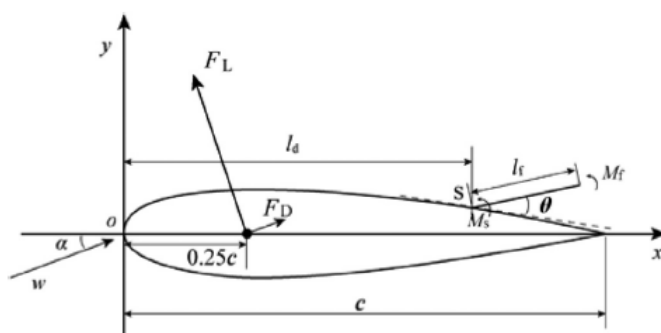
## LITERATURE SURVEY

- Flow separation can lead to stalling of the aircraft which can compromise the efficiency and safety of the aircrafts. Taking inspiration from bird feathers, WenxingHao et al[1]has aimed at studying the effect of adaptive flaps. The results were obtained by carrying out comparison between the lift coefficient values of clean and flap airfoil.
- Armaan Aditya et al [2] aims at studying various methodologies that are being used by researchers in order to deal with issues relating to various engines like turbojet, turbofan, turboshaft etc. If the value of drag coefficients decrease then also fuel savings can be achieved.
- Armaan Aditya et al [3]reviewed various types of smart materials that are used in different engineering branches for varied type of application. By using morphing wings the flaps can be eliminated completely because the wing will be able to change its area itself and obtaining variable  $C_L$ .
- Birds are natural flyers and their body is designed so as to give them maximum advantage while flying. Natural flyers like the birds and bats come in category of low Reynolds number flyers. Armaan Aditya et al[4]has aimed at studying the design of the natural flyers like birds, bats and insects which make them so efficient flyers.
- Srinivas G. et al [5]has aimed at proposing a new design modification for a wing based on a standard wing so that the new design can be more efficient than the standard design. Modeling of the airfoil was done using GAMBIT and ANSYS Fluent was used for analyzing the model. The results were validated against experimental wind tunnel data.

- In case of wind turbines the wings are referred to as blades and the cross-section of blade is the airfoil. Srinivas G. et al [6] has carried out Computational Fluid Dynamics (CFD) analysis of wind turbine blades. After modeling the blades of wind turbine from root to tip the blade is divided into several section. Lift and Drag coefficients are calculated for each section and at different Angle of Attacks (AOA).
- Delayed flow separation and resultant drag reduction in case of dimpled golf balls made aerodynamicists to apply this concept to aircraft wing. For studying the effect of dimples on the aircraft wing Awadh Kapoor et al[7] aimed at understanding “dimple effect” on a golf ball.
- M. Awasthi et al[8] performed experiments on a NACA 0012 airfoil and low Reynolds number flow was considered. Using pitot and hotwire probes, oil flow visualizations and velocity data were obtained.
- Talluri Srinivasa Rao et al[9] has conducted modelling and analysis of NACA 0012 airfoil in order to find the effect of design modification on the lift and drag characteristics of the airfoil.
- Robert Placeket al [10] conducted wind tunnel tests on laminar airfoil to study flow separation in subsonic and early transonic regimes of flow.

## METHODOLOGY

A NACA 0018 symmetrical airfoil was chosen for the analysis as the clean airfoil. Later, flap was modelled on the upper portion. The chord length ( $c$ ) of airfoil was 0.25m. The geometry of Flap Airfoil will be as shown in Figure 2.



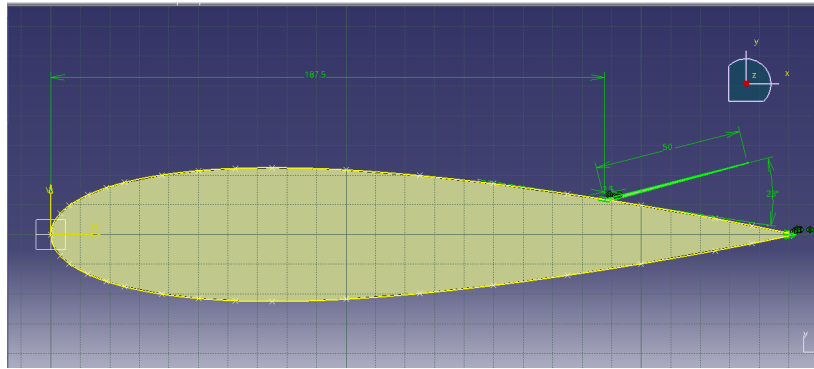
**Figure 2: NACA 0018 Airfoil with Flap [1]**

Where S= hinge between flap and airfoil

In the figure,  $l_f$ = length of the flap =  $0.2c$ ,  $l_d$ = distance between pt. o and S =  $0.75c$ ,  $\theta$  = flap angle =  $23^\circ$

## MODELLING OF AIRFOIL IN CATIA V5R19

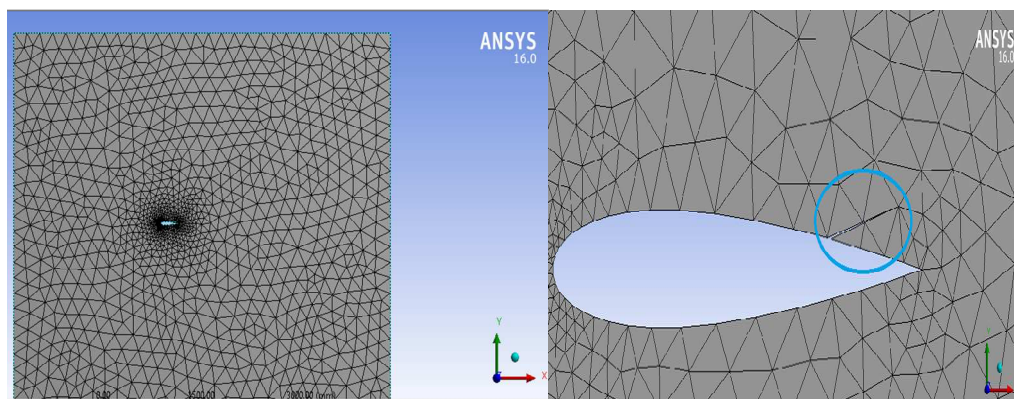
The airfoil coordinates were obtained from University of Illinois (UIUC) Airfoil Database. For clean airfoil the Airfoil coordinates are directly imported in ANSYS Fluent Design Modeler. For flap airfoil the coordinates were imported in CATIA and a flap with required dimensions was added. The geometry is shown in Figure 3.



**Figure 3: Model of NACA 0018 Airfoil with Flap in CATIA**

## CREATING A DOMAIN AND MESHING

A rectangular mesh was created having length as  $23c$  ( $=5750$  mm) and breadth as  $20c$  ( $=5000$  mm). The rectangular meshing was same for both clean and flap airfoil. The meshing was done using ANSYS Meshing and several Mesh control techniques like edge sizing, refinement etc. were given to get a fine mesh. Figure 4 depicts meshing of flap airfoil. It is necessary to give edge sizing on the flaps so that the flap doesn't vanish after meshing is done.



**Figure 4: Meshing of Flap Airfoil**

## BOUNDARY CONDITION SETUP

The simulation was carried out in FLUENT Solver and the required boundary conditions were put. As mentioned 2D steady SST  $k-\omega$  turbulence model was used to calculate the flow control performance. Flow parameters were as follows: Mach No.  $= 0.051$ , Re. No.  $= 3 \times 10^5$ . Because of low Mach number the density is assumed to be constant (as fluid behaves as incompressible). Relative Pressure was taken as 0 Pascal. The lift and drag characteristics of both clean and flap airfoil were calculated by varying the angle of attack from 12 to 20 degrees at steps of 2 degrees.

## RESULTS AND DISCUSSIONS

### Validation

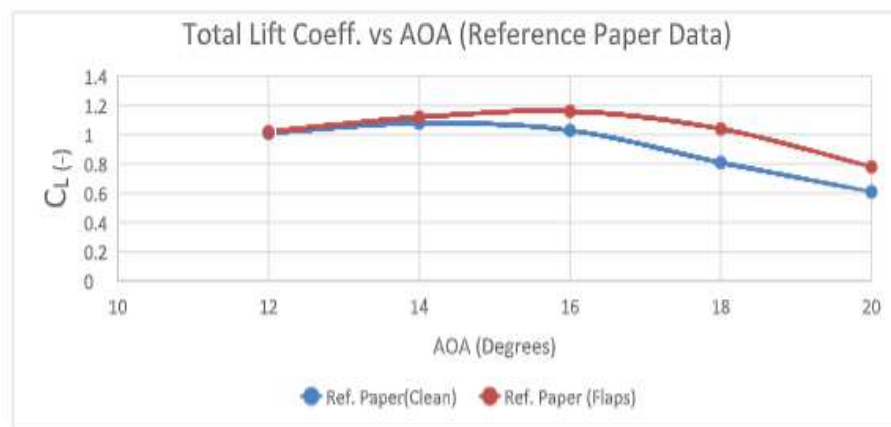
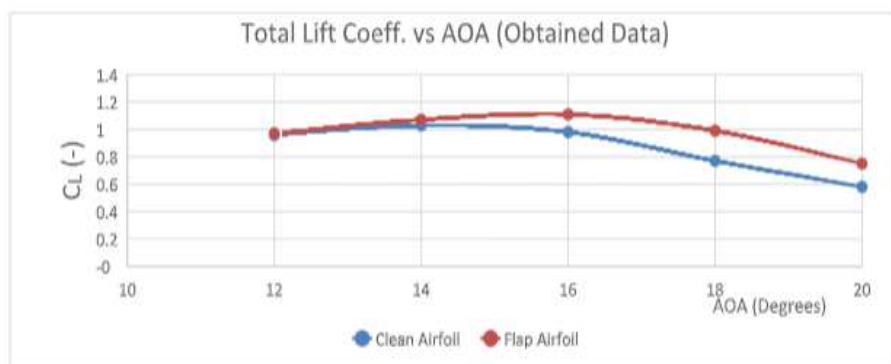
The results obtained for both clean and flap airfoil were compared with the experimental values obtained by Wenxing Hao et al [1]. The Reference values in [1] were tabulated along with values obtained in the numerical simulation done above. The compared values are as shown in Table 1. From Table 1 it can be seen that the experimental values from [1] and the values obtained from Numerical simulation are in close agreement with each other. The values in Table 2 have been plotted in Figure 5(b).

**Table 1: Comparison between Values in [1] and Values Obtained for Clean and Flap Airfoil**

CL for CLEAN AIRFOIL				CL for FLAP AIRFOIL			
AOA	Ref. Paper	Obtained Value	Error(%)	AOA	Ref. Paper	Obtained Value	Error(%)
12	1.01	0.96	4.950495	12	1.02	0.97	4.901961
14	1.08	1.03	4.62963	14	1.12	1.07	4.464286
16	1.03	0.98	4.854369	16	1.16	1.11	4.310345
18	0.81	0.77	4.938272	18	1.04	0.99	4.807692
20	0.61	0.58	4.918033	20	0.78	0.75	3.846154

**Table 2: Obtained Values for Clean and Flap Airfoil**

Obtained CL for Value for Clean and Flap		
AOA	Clean Airfoil	Flap Airfoil
12	0.96	0.97
14	1.03	1.07
16	0.98	1.11
18	0.77	0.99
20	0.58	0.75

**Figure 5(a): Graph Showing Variation of  $C_L$  with AOA as Obtained in [1]****Figure 5(b): Graph Showing Variation of  $C_L$  with AOA as Obtained in this Paper**

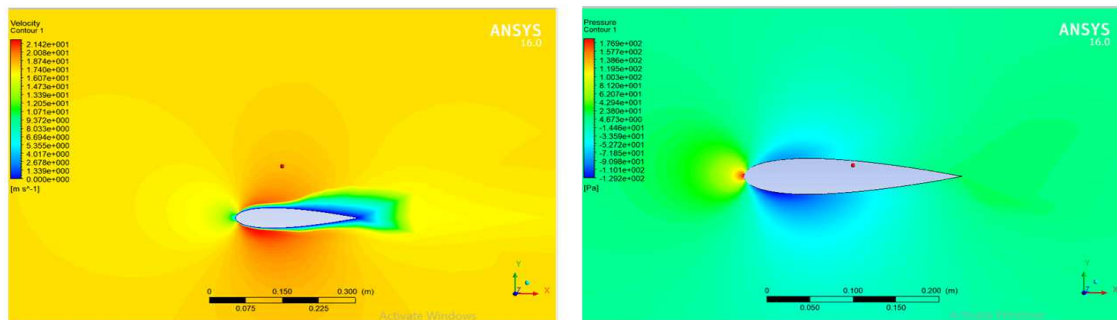
## ENHANCEMENT OF $C_L$

Table 2 shows that by adding flap to the clean airfoil an increase in the value of Lift Coefficient takes place. This has been depicted graphically in Figure 5(b) which clearly shows that the graph for flap airfoil is above the clean airfoil. Figure 5(a) which is a graphical representation of experimental data in [1] also shows similar variation as Figure 5(b) hence validating the results obtained in this paper.

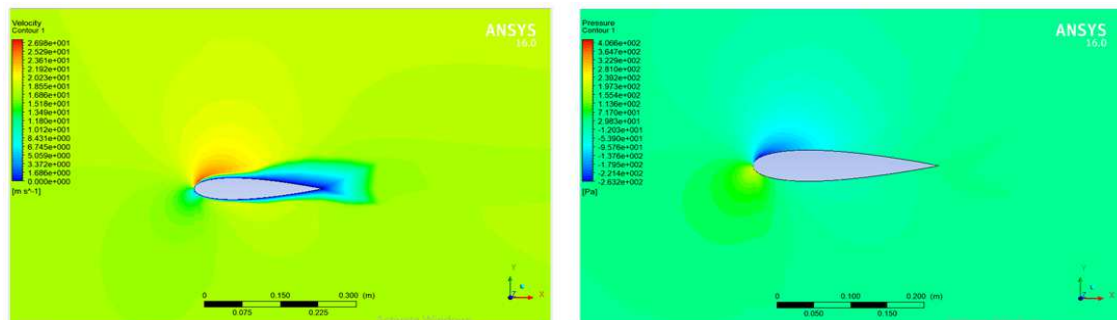
## VELOCITY AND PRESSURE CONTOURS OBTAINED AFTER SIMULATION

### Clean Airfoil

- $AOA = 0^\circ$



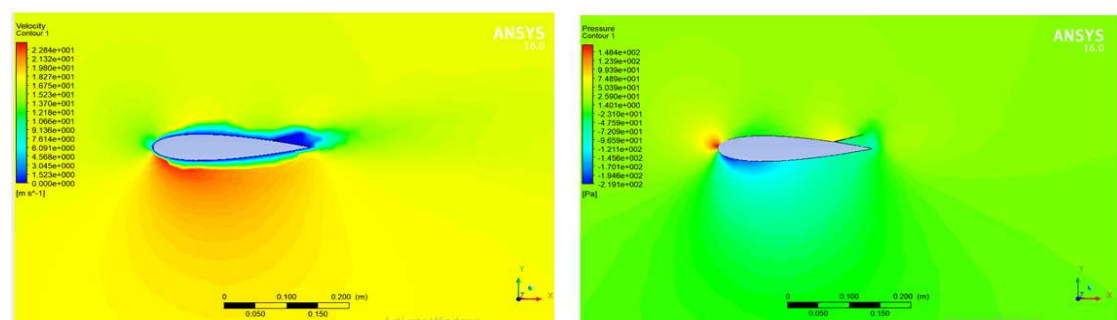
- $AOA = 18^\circ$



The simulation of clean airfoil at  $0^\circ$  and  $18^\circ$  showed that at  $AOA = 0^\circ$  the flow remain attached to the airfoil surface as expected. But from  $16^\circ$  onwards the flow separation begins due to which the flow separates from the airfoil surface and a loss in value of  $C_L$  is seen as depicted in Table 1.

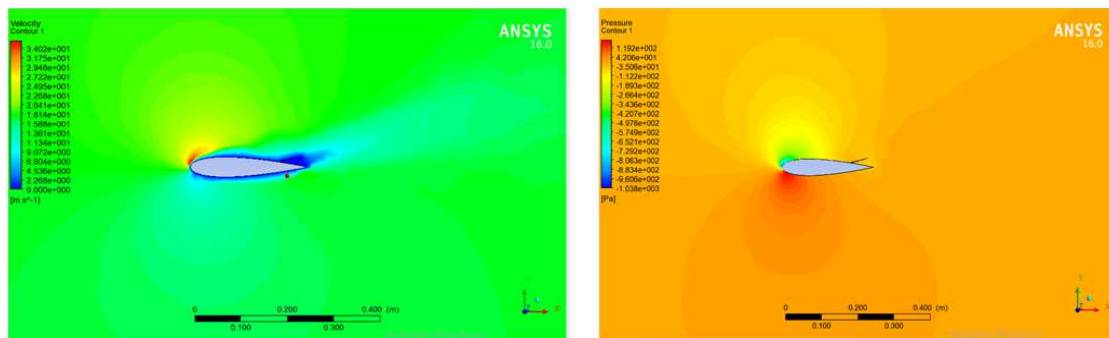
### Flap Airfoil

- $AOA = 0^\circ$





- AOA =  $18^\circ$



Flow simulations of flap airfoil at  $0^\circ$  and  $18^\circ$  show that the flow remains attached at  $0^\circ$  in the way as it is attached for clean airfoil. But in case of flap airfoil, flow separation starts at  $18^\circ$  unlike clean airfoil where flow gets separated at  $16^\circ$  only. The presence of flap allows the flow to remain attached for a longer duration.

## CONCLUSIONS

- In nature, birds delay flow separation by using adaptive flaps which come in use when birds are landing or face sudden gust. In the separation region due to the presence of backflow the feathers on the upper surface of bird's wing rise up thus delaying the flow separation and leading to a subsequent increase in lift.
- Adaptive flaps are being studied by researchers to be installed on the suction surface of the wing near the trailing edge. The aim is to develop adaptive flaps that will automatically rise, by the action of gravity and aerodynamic force, to delay flow separation. The numerical simulation done in this paper compares the lift coefficients of clean and flap airfoil where the flap is at  $23^\circ$ .
- The rising of flaps makes the separation point travel towards the trailing edge and thus aggravates the separation of flow. From [1] it was known that  $23^\circ$  is the optimal flap angle and from the numerical study done in this paper it was found that as the AOA increase from  $0^\circ$  to  $18^\circ$ , the value of Lift coefficient keep on increasing with flap angle fixed at  $23^\circ$ .
- The results obtained showed that for the clean airfoil the maximum lift coefficient occurred at  $14^\circ$  and was equal to 1.03. After the addition of flaps the value of lift coefficient changed to 1.11 and the maximum lift coefficient angle was increased to  $16^\circ$ .
- At  $23^\circ$  of flap angle the separation regions is split into 2 sections by the flap and each side having its own separation vortex.

## REFERENCES

1. W. Hao, Q. Ding, And C. Li, "Optimal Performance Of Adaptive Flap On Flow Separation Control," *Comput. Fluids*, Vol. 179, Pp. 437–448, 2019.
2. A. Armaan And G. Srinivas, "In Tune With Times: Recent Developments In Theoretical, Experimental And Numerical Techniques Of Aircraft Engines," Vol. 7, No. 2, Pp. 805–816, 2018.

3. G. Srinivas And M. G. B. P, "Aerodynamic Performance Comparison Of Airfoils By Varying Angle Of Attack Using Fluent And Gambit," Vol. 594, Pp. 1889–1896, 2014.
4. Awadh Kapoor, R. Jayakrishnan "Study And Design Of Golf Ball Like Dimpled Aircraft 2-D Wing And Effect On Aerodynamic Efficiency", *Proceedings Of The International Conference On Modern Research On In Aerospace Engineering*, 2018.
5. M. Awasthi, D. J. Moreau, And C. J. Doolan, "Flow Structure Of A Low Aspect Ratio Wall-Mounted Airfoil Operating In A Low Reynolds Number Flow," *Exp. Therm. Fluid Sci.*, Vol. 99, No. October 2017, Pp. 94–116, 2018.
6. Al-Waily, M. (2013). *Experimental and Numerical Vibration Study Of Woven Reinforcement Composite Laminated Plate With Delamination Effect*. *International Journal Of Mechanical Engineering (Ijme)*, Iaset, 2(5).
7. T. Srinivasa, T. Mahapatra, And S. Chaitanya, "Sciencedirect Enhancement Of Lift-Drag Characteristics Of Naca 0012," *Mater. Today Proc.*, Vol. 5, No. 2, Pp. 5328–5337, 2018.
8. R. Placek And P. Ruchała, "The Flow Separation Development Analysis In Subsonic And Transonic The Flow Separation Development Analysis In Subsonic And Transonic Flow Regime Of The Laminar Airfoil Flow Regime Of The Laminar Airfoil," *Transp. Res. Procedia*, Vol. 29, Pp. 323–329, 2018.